National Park Service
U.S. Department of the Interior

Badlands National Park
Interior, South Dakota

Geology Field Camp Guide:
Two Days in the White River Badlands for College Level Study

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Introduction

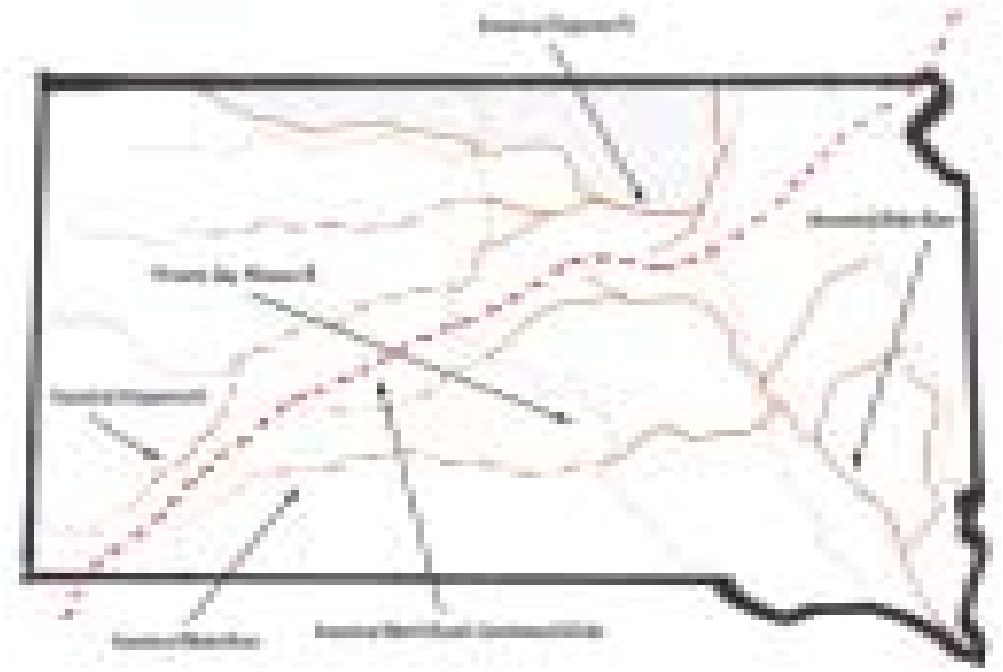
Badlands National Park lies in the middle of the Unglaciated Missouri Plateau section of the Great Plains Physiographic Province. A field trip to the Badlands and surrounding areas affords college age students a chance to see a variety of surface processes. Ancient drainage systems, Oligocene mammalian fossils and sharply eroded buttes, pinnacles, and spires are the main attractions of the Badlands. Its distinctive topography is developed upon unresistant sediments of late Cretaceous, Eocene and Oligocene age. This guide will omit fossils from its route. The fossil record is so immense that years could be (and have been) spent in the Badlands studying fossils.

Cover Photo:
Yellow Mounds Paleosols of the Chadron Formation (foreground) with Brule Formation (background)
Used with permission from Badlands Natural History Association

Plan on spending two days in Badlands National Park in order to fully enjoy and complete the tour that this guide presents. Students should be familiar with the Great Plains Province, its creation and dissection, with erosional processes, and with the effect of glaciation on the continent's drainage. This background knowledge will make the stops all the more enjoyable.

The Geology of the White River Badlands

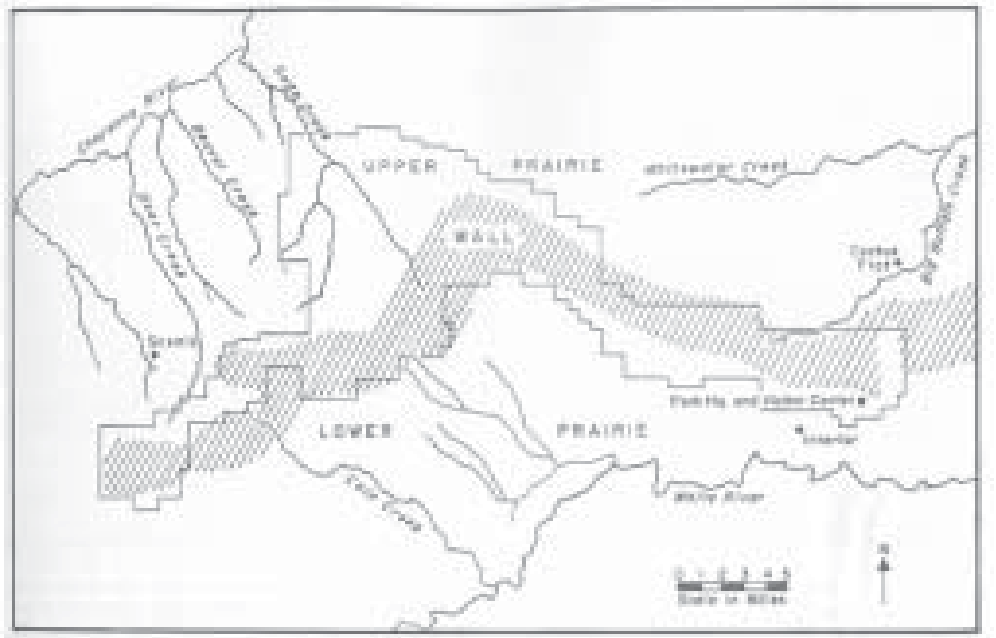
The Missouri River more than splits the state geographically: it represents a geologic and economic boundary. East of the Missouri, glacial soils and more prevalent rainfall allow for agriculture. Most of the state's population lies east of this boundary. To the west, insufficient rainfall (west of the 100th meridian) makes ranching, mining, and tourism the principal mainstays of the economy. Before glaciation, much of the state received more rainfall than today, and the landscape was far lusher. All rivers drained eastward, past the current Missouri River, to the ancestral White River. The ancient continental divide trended southwest to northeast, and separated drainage north to the Hudson Bay from that to the south to the Gulf of Mexico. Today the northern continental divide dips just slightly into North Dakota and Minnesota, where the Red River of the North drains those areas.



Locally, deposition of the White River Group in the Big Badlands of South Dakota was the result of the interaction of tectonics and climatic change. The Black Hills were uplifted during the latter phases of the Laramide Orogeny resulting in the exposure, weathering, and erosion of Paleozoic and Mesozoic sedimentary rocks. Consequently, faults radiating away from the Black Hills created a slightly northwest-southeast trending asymmetric basin hinged on the north along the Sage Fault and on the south along the Sandoz Ranch, White Clay, and Pine Ridge fault system (Clark and others, 1967). This basin was filled by sediments brought in by fluvial systems from the Black Hills and by eolian processes, including rare volcanic ashfall events (Ritter and Wolff, 1958; Seefeldt and Glerup, 1958; Nicknish and Macdonald, 1962; Clark and others, 1967; Clark, 1975). Paleosols indicate an overall paleoclimatic trend toward increasing aridity during deposition of the White River Group in the Big Badlands (Retallack, 1983). This climatic shift is indicated by a decrease in the size of root traces within the paleosols and corresponds to a change from forested environments to open savannas. Paleosols at the base of the sequence resemble modern soils formed under humid, forested conditions Progressing upwards, paleosols gradually change to types resembling those found in drier, grassland ecosystems (Retallack, 1983).

Today, the Badlands "Wall", composed of the rocks of the White River Group, is an east-west trending escarpment that is retreating to the north. The highest saw tooth ridges of the wall represent a drainage divide between the White River to the south and the Cheyenne River to the north. The wall also represents a separation in landscape. To the north of the wall, along Interstate 90, is the upper prairie. The upper prairie is an undissected area of flat grassland that stretches far to the north. To the south of the wall (and including the entire Sage Creek Wilderness Unit) is the lower prairie. Close to the south side of the wall, the transition to the lower prairie is abrupt, with sod tables, intermittent stream channels and minor buttes jutting up from the grassland. This boundary area extends about three miles south of Cedar Pass to the White River. Elsewhere, and particularly on the Buffalo

Gap National Grassland, this area peters out to the lower prairie at about 3 miles from the wall, at which point the lower prairie serves as the floodplain for the White River. The downcutting of the White River, the retreat of the escarpment, and its erosion into badlands topography has created the landscape visible today. *(Primary Source: Terry, Dennis O., Dakotera, 1998)*



Before You Leave Home:

Obtaining a Fee Waiver

Before you leave your home base or campus, you should request an educational fee waiver. **To apply for a waiver send a letter on official letterhead stationary at least two weeks prior to arriving at the park. Waivers are only obtainable through the fee program manager and NOT from the entrance station rangers upon your arrival.**

To qualify for recreational fee waivers, programs or outings conducted for educational or scientific purposes by schools or other educational institutions must:

- Provide documentation of official recognition as an educational institution by a Federal, State, or Local government entity.

- Statement of visit purpose. You are required to submit a statement as to the purpose of the visit. This purpose must relate to your academic institution's curricula, particularly the name of the course supported by this visit. Simply stating the visit is for "educational purposes" is insufficient. In general, fee waivers are available only to groups, such as field camps.

- Have a direct relationship between the visit purpose and the facility use. Use of any recreational facilities for which a waiver is requested must relate directly to the educational purpose of the visit.

To apply for a fee waiver for Badlands National Park or for more information write to:

Badlands National Park
Fee Program Manager
PO Box 6
Interior, South Dakota 57750

Questions may also be directed to the Fee Program at (605) 433 - 5235.

Collecting Is Not Allowed Without a Park-issued Permit

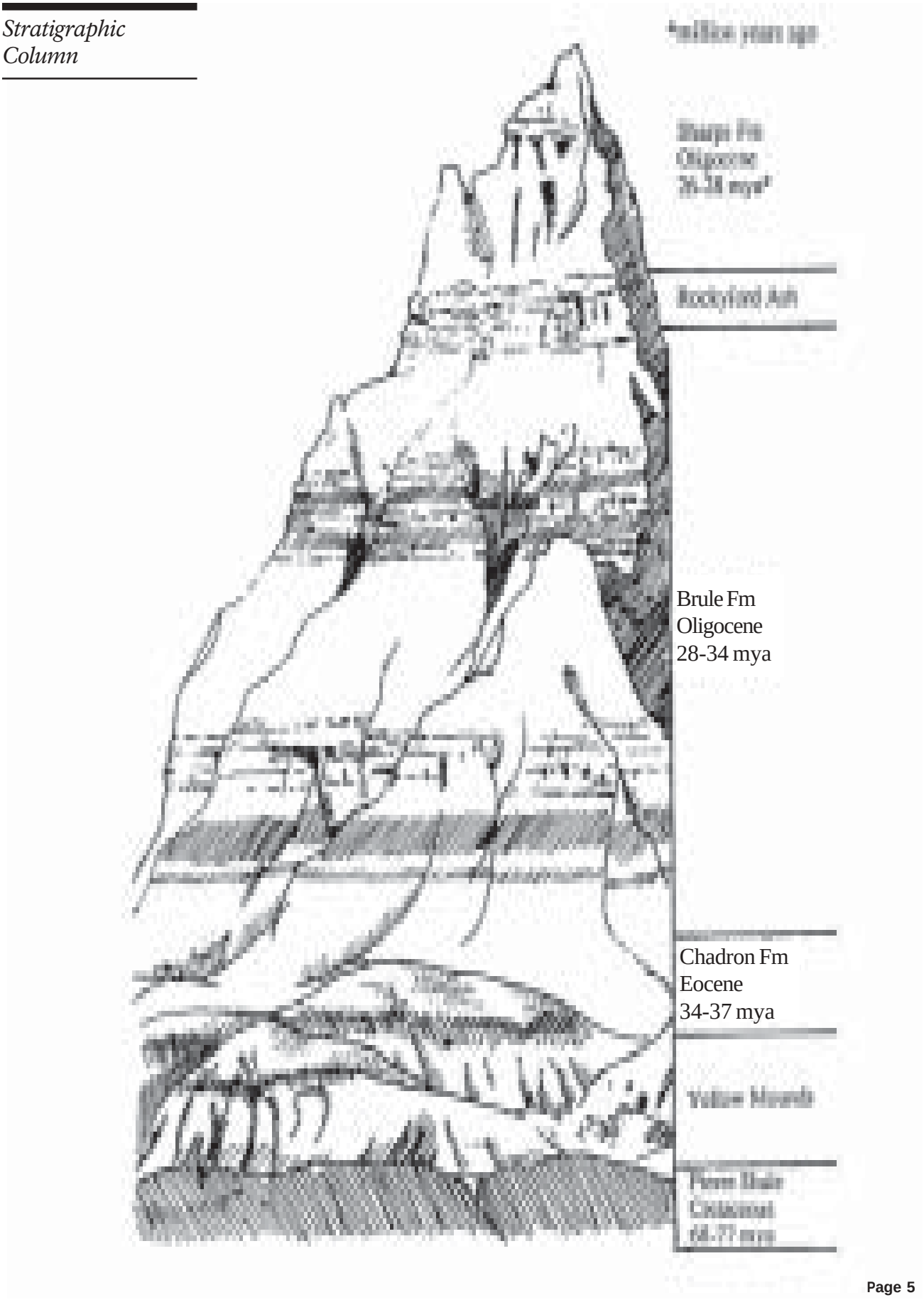
Before you arrive be sure to remind your students of the laws surrounding collecting in National Parks. It is illegal, and punishable, to remove any rock, fossil, or plant from Badlands National Park. Furthermore, please be kind to the resources of the park and leave rock hammers at home.

Rock hounds in your group may collect from the Buffalo Gap National Grassland. The law allows for removal of invertebrate fossils only from the National Grasslands. Please purchase a Grasslands Map at the visitor center so that you can insure you are collecting from public and not private land.

Staff Guided Tours

In general, park staff is not available for guided tours. In particular, park subject-matter experts, such as the park paleontologist, are working in the field and cannot be scheduled for special visits. Group leaders interested in a general introductory Fossil Talk and Leave No Trace orientation may contact the Education Specialist at (605) 433 - 5242 to inquire into staff availability. A minimum of four weeks advance notice is required with no guarantee of staff available. Keep in mind that these programs are geared toward the general public, not college level academic study. history. These topics, while not about geology, will allow students to get a better sense of the immense significance of the park.

Stratigraphic Column



Tour Basics

The tour begins from the Cedar Pass Campground and is split between two days with the group arriving the night before the first field day. For example, a group arriving on Monday evening should spend that evening at Cedar Pass Campground, then follow the Day One agenda on Tuesday, ending at the Sage Creek Campground for Tuesday night. The second day (Wednesday) begins from the Sage Creek Campground and takes field camps west toward the Black Hills.

The Cedar Pass Campground collects camping fees. Group campsites must be reserved in advance by calling (605) 433 - 5235 for rates. Once your camping fee is received, you will be sent a confirmation letter with your assigned campsite number.

The Sage Creek Campground is free and does not require any reservations. However, it lacks water and designated campsites, providing an open area with scattered tables and vault toilets.

Feel free to adopt and omit spots at will. Nothing says that this tour could not be done in one day, or ten. Pull over anywhere that you see fit; time is built into this tour for instructors to make other stops. Badlands National Park permits hiking anywhere in the park and so visitors are not constrained to roads and trails. While this tour is designed to minimize driving, the stops may be seen in any order. Finally, take your time, and have fun, Badlands has more to offer than meets the eye.

Safety Hazards

You may explore off trail in Badlands National Park. Keep the following cautions in mind:

- Wear boots with ankle support and long pants to avoid injuries from the rough terrain and the common prickly pear cactus.
- Climbing of the buttes is allowed but is dangerous. The soft sediments of the Badlands crumble easily. Be sure that students are aware of the danger of climbing.
- Use of rock hammers or other resource extraction is not permitted.
- Prairie rattlesnakes are also common. Look into cracks and crevices before placing hands and feet to avoid bites.
- Each person should carry one gallon of water per day, as well as high energy snacks.
- Hats, sunscreen, and sunglasses are a must year round.

Day One

Stop #1: The White River

Driving Directions: Cedar Pass Campground to White River: From the Campground make a left and leave Badlands National Park. Head toward the town of Interior. Take SD 44 East toward Wanblee. The White River will be 1 mile past Interior. **Distance: 3.2 miles**

The White River heavily laden with sediments

The White River is so named for the brownish color and thickened consistency of its waters. Colloidal dispersion keeps the clays of the Badlands from settling out of suspension. The climate of the Badlands should be evident from the jagged cobbles and boulders that line the channel of the White River. Notice how large the floodplain of the White River is, a testament to springtime days. Violent, sudden thunderstorms during spring and summer fill the White River to bankfull and so give it incredible power to undercut its banks, down cut its bed, and transport the resultant load.

The high escarpment on the south side of the river is the Pine Ridge Escarpment. Immediately to the right of the KOA campground, this scarp is very visible. Farther on, SD 44 continues up the terraced portion above the scarp to the high plains. This boundary is the border between the Missouri River Plateau section and the High Plains section of the Great Plains Province. The High Plains section is relatively undissected by drainage, and through stream capture, has remained isolated. Capped by the Oglala Formation, this area represents the plains as they were first deposited in the form of a gentle east dipping apron of sediment extending from the Rocky Mountain front out to the central lowland.

Stop #2: Ben Reifel Visitor Center

Driving Directions: White River to Ben Riefel Visitor Center: From the White River head west on SD 44 back to Interior and up to Badlands National Park. Pass the Campground from which you came and continue on the Badlands Loop road toward the town of Cactus Flat. You will pass the Cedar Pass Lodge and then the visitor center on your right. **Distance 3.5 miles.**

Ben Reifel Visitor Center

The Ben Reifel Visitor Center includes restrooms, exhibits, and an orientation film. If you scheduled a staff-led program, meet them here. Postcards and books may also be purchased at the visitor center.

Stop #3: Old Northeast Road

Driving Directions: Ben Reifel to Old Northeast Road: From the visitor center make a right and continue on SD 240, the Badlands Loop Road, towards CactusFlat and exit 131 off I-90. Travel through Cedar Pass for 1 mile and make a left on to the Old Northeast Road.

This stop provides a view of the stratigraphic relationships of the Poleslide Member of the Brule Formation, the Rockyford Ash Member of the Sharps Formation, and a portion of the overlying Sharps Formation. For a description of these units and the rest of the White River Group, consult the stratigraphic column on page 6. The Sharps Formation is composed mainly of massive, poorly consolidated, pinkish tan siltstones containing many calcareous concretions and channel sand, gravel, and thin limestone interbeds (Harksen and others, 1961). The base of the Sharps Formation is marked by Nicknish and Macdonald's (1962) Rockyford Ash. Paleosols of the Pinnacles, Ogi, and Samna series occur within the Sharps Formation (Retallack, 1983). Samna Series paleosols resemble Inceptisols, and likely supported forbs, grasses, and shrubs on distal floodplains.

Typical appearance of Brule Formation.
Location: Directly across from Ben Reifel Visitor Center

The Brule Formation in the Big Badlands consists of the Scenic (lower) and Poleslide (upper) Members (Bump, 1956). As originally defined by Bump (1956), the Scenic Member contains beds between the top of the Chadron Formation and the top of the upper nodular layer of Wanless (1923). The 30 m of the Scenic Member exposed here is composed of cliff-forming beige, tan, and brown mudstone, siltstone, and sandstone with thin limestone interbeds (Clark and others, 1967). The basal part of the Scenic Member contains the Metamynodon channels which were named for fossils of the semi-aquatic rhinoceros commonly found within them (Wortman, 1893). Color banding within the Scenic Member has been attributed to paleosols of the Zisa, Ohaka, Conata, Ogi and Gleska series (Retallack, 1983). Zisa Series paleosols resemble modern Entisols and likely supported early successional vegetation in near-stream environments. Paleosols of the Ohaka, Conata, and Ogi Series resemble modern Inceptisols and are only slightly better developed than Entisols. Ohaka Series paleosols likely formed within valley floodplains that supported herbaceous and early successional vegetation. Conata Series paleosols likely formed on distal floodplain areas and terraces that supported savanna woodlands and herbaceous vegetation. Gleska Series paleosols are strongly developed and resemble modern Alfisols that support woodland vegetation on floodplains (Retallack, 1983). According to Clark and others (1967), the "lower nodular zone", which usually marks the base of the Scenic Member, can be divided into a "swampy plains facies", an "open plains facies", and a "near stream facies". Macdonald (1968) and Emry and others (1987) question the validity of these facies classifications. The upper portion of the Scenic Member is sometimes marked by a band of nodules that Wanless (1923) referred to as the "upper nodular zone". These nodules do not occur uniformly throughout the upper portion of the Scenic Member, and where they are absent this stratigraphic position is marked by clay (Wanless, 1923). Recent reviews of the "nodular zones" in Nebraska (Terry and others, 1995; Wells and others, 1994, 1995; LaGarry and LaGarry, 1997) advocate abandoning their use in regional correlations.

The contact between the Scenic and Poleslide Members is marked by a change to finer grained eolian sediments. According to Wanless (1923), the Poleslide Member fines upward from sandy siltstone to claystone and has occasional sandstone bodies throughout. In contrast to the Scenic Member, the Poleslide Member has a more massive appearance. Pedogenic modification is prevalent and includes paleosols of the Ogi, Wisangie, Zisa, Gleska, and Pinnacles series (Retallack, 1993). Wisangie Series paleosols resemble modern Inceptisols and likely supported a savanna woodland flora, herbaceous ground cover, and scattered trees on dry portions of proximal floodplains (Retallack, 1983). Pinnacles Series paleosols resemble modern Aridisols and likely supported shrubs, forbs, and grasses on dry,

distal levees. The unit is approximately 47 m thick in Dillon Pass and is overlain by the Sharps Formation of the Arikaree Group (Retallack, 1983).

The channel sands and gravels are evidence of the great east draining rivers that once crossed the state. The ancient Cheyenne, or Bad River, may easily have deposited these gravels, but at a much higher elevation than today.

End of Boardwalk, Door Trail

Stop #4: Door Trail

Driving Directions: Old Northeast Road to Door Trail: Make a left back on to SD 240, the Badlands Loop Road. Continue until you reach the trail heads of the Door, Window, Notch, and Castle Trails. Make a right into this parking lot. Go to the left section of the lot for the easiest access to the DoorTrail.

If you have not yet noticed all of the greenish vertical intrusions that criss-cross the Badlands, the entrance to the Door Trail offers a fine vantage point from which to view these features. Locally they are called clastic dikes but some are better described as veins. These features have a variety of much disputed origins. Debate surrounds both the origin of the fissures and the material which fills them. The fissures may have formed by stretching of the strata during regional uplift about 5 mya. Another suggestion is that de-watering of clays led to contraction and formation of shrinkage cracks. Some of the fissures are infilled with veins of chalcedony, a form of silica that may have been introduced in solution by groundwater. Other fissures are infilled with sediment, often white ash from the upper Brule and lower Sharps Formations that may have been washed or blown into the cracks. Alternatively, the sediment may have been carried upwards along the cracks as water escaped from saturated beds which were put under hydrostatic pressure by superincumbent strata. It is likely that a combination of the explanations apply to the clastic dikes and mineral veins of the Badlands. Where more resistant the dikes and veins form ridges that cross buttes and gullies alike.

Try to locate where the dikes have eroded into a platy pile of chalcedony. Very locally, this detritus acts as a shield near the source, and protects the buttes from further erosion.

Stop #5: Interior Road

Driving Directions: Door Trail to Interior Road: Make a left out of the parking lot back on to SD 240, the Badlands Loop Road. Continue past the visitor center and follow signs that direct you to I-90, exit 110 ,and Wall. The road to Interior will be on your left. Shortly after passing the Saddle Pass Trailhead turn left on to the Interior Road. **Distance 8 miles.**

A normal fault is exposed in the Brule Formation directly south of the Interior road. This fault can be viewed from three directions. When viewed from the south and west, an unusual combination of topography and fault geometry create the appearance of reverse separation. Several northwest/southeast-trending faults can be observed on both sides of SD 240 between the Interior road turnoff and the Ben Reifel Visitor Center in Cedar Pass. These faults are part of a system initiated to relieve stress during the Black Hills uplift and have been activated by subsequent regional uplift.

Pig Dig Excavation, 2003 Field Season

Stop #6: The Pig Dig

Driving Directions: Interior Road to Pig Dig: Make a left back on to SD 240, the Badlands Loop Road. Continue just past Conata Basin Overlook. Turn left onto Conata Road (road is gravel). Parking lot for site and picnic area located approximately ¼ mile on right hand side. Short walk to excavation site. **Distance 15 miles.**

Fossils may not be the focus of this trip, but this site is one of the larger fossil finds in the park, and deserves a look. The Pig Dig is a very dense accumulation of Orellan vertebrate fossils near the base of the Scenic Member of the Brule Formation. This accumulation (ca. 4500 bone elements) is unique in the Badlands not only in the density of bone at this site, up to 200 elements/m^2, (Stevens, 1996), but also in the manner in which the bone is preserved.

According to Terry (1996), the Pig Dig bone bed formed on a floodplain within a depression proximal to a former channel. This is supported by the presence of a lenticular sand body, interpreted as a crevasse splay deposit, the frequent occurrence of silt and fine sand laminae within claystone deposits, and the lenticular geometry of individual depositional packages

within the bone bed. The coloration of individual units within the Pig Dig is not the result of ancient soil formation.

The most likely explanation for the genesis of this bone bed is the death and accumulation of animals around a watering hole during drought conditions. This scenario would explain the lack of any preferred orientation of bone elements, the articulated to isolated nature of bone elements, bone processing, the presence of high angled bones and possible foot/hoof prints due to trampling, the grouping of some animals (entelodonts), and the lack of pedogenic modification.

Stop #7: Dillon Pass

Driving Directions: Pig Dig to Dillon Pass: Follow Conata Road back to SD 240, the Badlands Loop Road and turn right. Pull off at the first road stop immediately to your right. **Distance .1 miles.**

This stop provides an excellent vantage point from which to examine the lower part of the White River Group. These outcrops form the basis for comparisons and correlations with lithostratigraphic units in northwestern Nebraska. Also visible from this location are the Sage Arch and the Dillon Pass Fault. The Sage Arch has a northwest-southeast trend and gently tilts the White River and Arikaree Groups to the southwest and northeast.

Associated with the Sage Arch is the Dillon Pass Fault. In the Dillon Pass area, this fault downthrows units to the southwest, resulting in the juxtaposition of the greenish-gray hummocky mudstones of the Chadron Formation, with the brightly colored, pedogenically modified sediments of the "Interior Zone" within the Pierre Shale. The Dillon Pass Fault is likely associated with faulting that forms the northern hinge of the asymmetric basin described by Clark and others (1967).

A paleovalley formed by the fall of relative base level east of the Black Hills during the Eocene was the site of deposition for Clark's (1937, 1954) Ahearn, Crazy Johnson, and Peanut Peak Members of the Chadron Formation in South Dakota. This paleovalley, Clark's (1937, 1954) "Red River Valley", incised through the Chamberlain Pass Formation and Yellow Mounds Paleosol into unaltered Pierre Shale. The Ahearn Member consists of red and green sands and clays filling the bottom of the paleovalley. Quartz, quartzite, and granite gravels mark its base. The overlying Crazy Johnson Member is 12-15 m of greenish clays and sands containing fossils of brontotheres, rhinoceroses, horses, and entelodonts. It is overlain by the Peanut Peak Member, which consists of 6-9 m of massive buff and green claystones containing discontinuous limestones and green sandstone lenses.

The Yellow Mounds Paleosols

Stop #8: Yellow Mounds Overlook

Driving Directions: Dillon Pass to Yellow Mounds Overlook: Continue east on SD 240, the Badlands Loop Road. **Distance .1 miles.**

Yellow Mounds Overlook offers a striking view of the yellow mounds developed on the Interior Paleosol. A brightly colored zone of ancient soil formation marks the base of the section. This zone has had many names, including the "Interior Phase" (Toepelman, 1922; Ward, 1922), "Interior Formation" (Wanless, 1922), "Interior Paleosol Complex" (Schultz and Stout, 1955), "Eocene Paleosol" (Pettyjohn, 1966), "Interior Zone" (Clark and others, 1967), and "Interior Paleosol" (Harksen and Macdonald, 1969a; Martin, 1987). Based upon root traces, nodules, soil horizons, and vertical geochemical trends, this "zone" is composed of two separate paleosols (Retallack, 1983). The lower of the two paleosols, the Yellow Mounds Paleosol Series, developed on the subaerially exposed Pierre Shale after the retreat of the Cretaceous Interior Seaway. The Yellow Mounds Paleosol Series is easily recognized as the bright yellow and orange zone, up to 26 m thick in some locations, that gradually gives way to unaltered Pierre Shale with increasing depth. The upper paleosol, the Interior Paleosol Series, subsequently developed on fluvial overbank deposits overlying the Pierre Shale. The Interior Paleosol Series is easily recognized as the reddish band above the Yellow Mound Paleosol Series at the top of the "Interior Zone." The Interior Paleosol Series is 2.6 m thick at this stop (Retallack, 1983).

According to Retallack (1983), the Yellow Mounds Paleosol most closely resembles a modern Ultisol. Soils of this type form in warm, humid climates having a dry season (Soil Survey Staff, 1975). It has been estimated that Ultisols require 10,000 to possibly several million years to form (Cady and Daniels, 1968; Buol and others, 1973; Birkeland, 1974; Soil Survey Staff, 1975). The overlying Interior Paleosol Series closely resembles a modern Alfisol. Modern soils of this type form on well-drained upland areas under hardwood forests. They are characterized by translocated clay accumulations at depth, and likely require at least 15,000 years to form (Soil Survey Staff, 1975).

Stop #9: Pinnacles Overlook

Driving Directions: Yellow Mounds to Pinnacles: Head west on SD 240, the Badlands Loop Road, to Pinnacles Overlook. **Distance 3 miles.**

This stop provides a panoramic view of the upper part of the White River Group (foreground) and the Black Hills (background). Only the Sharps and Brule Formations are well exposed here. Small exposures of the Chadron Formation are visible in deep drainage cuts in the distance.

The bottom tier of this overlook rests upon the basal Rockyford Ash Member of the Sharps Formation. The Rockyford Ash is dated at approximately 30 mya on the basis of comparisons to likely equivalents in Nebraska (Tedford and others, 1996). It is about 5 m thick here (Retallack, 1983) and varies between 0-17 m thick across the region (Nicknish and Macdonald, 1962). It is noted for numerous crosscutting clastic dikes and "pipey" concretions, some of which were viewed earlier.

The first day of the tour ends here. Wall, SD is only 8 miles away from this point. A drive to Wall to pick up food and water for the evening is advisable if it is needed. Please be reminded that Sage Creek Campground has no potable water.

Stop #10: Sage Creek Primitive Campground

*Driving Directions: P*innacles Overlook to Sage Creek Campground: Continue west on SD 240, the Badlands Loop Road. A sign will indicate Sage Creek Rim Road. Make a left on to Sage Creek Rim Road (gravel road). The campground is 12 miles from this turnoff. **Distance 12.2 miles.**

Be aware, Sage Creek Rim Road is a dirt road. Please drive carefully! Sage Creek Campground is a primitive campground since no water is available and there are only pit toilets. Roberts Prairie Dog Town, midway between SD 240 and the campground, provides a fun island of biology in a tour dedicated to the geology of the Badlands.

Before the sun sets, or early in the morning, take a walk up the Middle Fork of the Sage Creek, or up the Sage Creek itself. Erosion by the Creek provides exposures of unaltered Pierre Shale. This is also a good place to observe marine fossils in situ.

Sage Creek Campground

Stop #1: Sheep Mountain Table and Cedar Butte
Driving Directions: From Sage Creek Primitive Campground to Sheep Mountain Table: From the Sage Creek Campground, make a left out of the access road and continue heading south on the Sage Creek Rim Road; this is Pennington County 590. Shortly after you depart the campground, you will leave Badlands National Park. County Road 590 will intersect SD 44 near the town of Scenic. At this junction, make a right, Scenic will be in view. Make a left at the sign that reads "Badlands National Park, South Unit, 20 Miles". This will take you to Pennington County 589, and through the town of Scenic. 4 miles after passing through Scenic, you will see a sign that reads "Sheep Mountain". Make a right at this sign. This is an unimproved dirt road so drive carefully. From this point, it is 8 miles out to the edge of Sheep Mountain Table. Road conditions vary along this road. A standard van or rear wheel drive vehicle should have no problem if the road is taken cautiously. Note that this road can be impassible if it is wet. If at any point your vehicle can go no farther, get out and walk as this is a site you do not want to miss. **Distance: 17.5 miles.**

Sheep MountainTable is a vast mesa, which affords spectacular views of the lower prairie and the Badlands. Erosional processes have worked differently here, and it will become evident very quickly. The road at the top of Sheep Mountain will meander until it comes to the edge of the Table. The view here provides a look at the upper Brule formation. Continue on the road out to Cedar Butte (the end of the Table). The road will narrow considerably, and off to your left you may view the edge of the Table and the prairie below. Stop here and see if you can find the hoodoos forming in some of the Brule. Continue on out to Cedar Butte. The road will split in many directions and tracks will be visible everywhere. It is best to park the car and walk to the edge. Here the Brule Formation erodes vertically in flutes. This spectacular erosional pattern is reminiscent of the Claron Formation (the Pink Cliffs) of the Colorado Plateau.

The spectacular setting of Sheep Mountain Table may make it a spot where students will want to spend some time, so feel free to do so.

Stop #2: BIA 27
Driving Directions: Sheep Mountain Table to roadside: Continue back on the Sheep Mountain Table road to County Road 589. Make a right on to 589. You will cross into the Pine Ridge Indian Reservation; here County Road 589 becomes BIA 27. Continue south on BIA 27 for about 5 miles and pick a spot to pull over near the extensive sod tables.

The creation of Badlands topography requires specific conditions. The first requirement is a nearly homogenous layering of fine textured sedimentary rocks. Secondly, semi-arid conditions are needed in which infrequent but severe downpours of torrential rain often accompany thunderstorms. The third requirement is the presence of shallow rooted vegetation that provides little protective cover to the underlying soil and sedimentary rock. Finally, a drainage system is needed that is actively downcutting to a base level significantly lower than that which shaped the original Plains landscape.

When one or more of these requirements is missing, badlands topography is not easily created. The sod tables seen on the left, and all to the east of BIA 27 are the result of two of these factors, vegetation and base level, being modified from the ideal. Denser vegetation here provides some protection against erosion, much like a caprock protects a butte from final disintegration. The close proximity of this area to the White River has meant that there is little height difference between the general landsurface and the local base level. As a consequence downcutting by the White River has been less severe.

Stop #3: Coffin Butte
Driving Directions: BIA 27 to Coffin Butte: Continue south on BIA 27, and pass Badlands National Park, White River Visitor Center. At BIA 2 make a right. BIA 2 is a dirt road, so please drive carefully. **Distance 22 miles.**

The pillared landscape along BIA 27 is continued along BIA 2. Coffin Butte, like Sheep Mountain Table, is a more resistant mesa. Junipers and cedars provide the extra root protection that allows this table to remain so untouched relative to the surrounding landscape. It is not hard to see how this landmark received its name. It is more difficult to explain its formation. Coffin Butte bears a striking resemblance to El Capitan Mountain in the Guadeloupe Mountains of west Texas and New Mexico. However, El Capitan is made

of resistant marine limestone whereas Coffin Butte is composed of the same soft claystones and mudstones as the rest of the Badlands. This high table has its own talus slope which creeps to the very bottom of the "coffin" and conceals the Lower Brule formation.

After Badlands National Park: Toward the Black Hills

Western South Dakota has a very diverse landscape. You are more than encouraged to continue on to other locations in the Great Plains. Some recommendations are presented here to help guide you to some very important geologic stops.

Stop #1: Cheyenne River along SD 44

From Badlands National Park, drive west on SD 44 through the town of Scenic. Four miles past Scenic, you will enter the Cheyenne River Valley. Driving along SD 44, the unglaciated plateau drops suddenly into the broad, terraced Cheyenne River valley. Crossing the river raises the question, how did such a small river create such a large floodplain?

Ancestral drainage systems once drained an area of wetter climate than today. Increased water volumes helped shape this valley then. Later, ice-sheets crept south and west across the state and deflected the Missouri to its present course from an earlier course which lay to the east. The surface beneath the ice-sheets was deeply scoured. East flowing tributaries, such as the Cheyenne could advance no farther than the edge of the ice-sheet at which point they were deflected south parallel to the ice margin and began downcutting a new course for the Missouri to a lower base level. When the ice-sheet retreated, the east flowing rivers, including the Cheyenne continued to join the new south flowing course of the Missouri Some of the terraces of the Cheyenne that you see today were cut to the new base level after the retreat of the continental ice sheet.

The Cheyenne River easily cut into the soft unaltered Pierre Shale. Today, the Pierre Shale is exposed by slumping. Textbook examples of slumping are seen all across the valley. Black scarps indicate where undercutting has undermined the stability of the slopes, causing them to slump. Look across the valley, away from the road, with your binoculars: notice the curved fence line, a result of this process.

Stop #2: Needles Highway

Highway 87 South becomes the Needles Highway off of US 16, in Custer State Park. The Precambrian crystalline core of the Black Hills is exposed all along the Needles Highway. Vertical fractures, exploited by freezing and thawing, have created the tall, narrow rock pillars or needles that give the highway its name. If driving a larger vehicle, watch your height clearance in tunnels.

Stop #3: Dakota Hogbacks

Driving along I-90 west toward Rapid City, small hills become visible in front of the Black Hills. These are the Dakota Hogbacks. Do not stop along the Interstate. Consult a local map for best access.

Uplift of the dome of the Black Hills caused the overlying Mesozoic sedimentary strata to dip outwards in all directions. Subsequent erosion of these strata has created a concentric cuesta, with inward facing scarp, upon the more resistant Cretaceous Lakota Sandstone beds. In some places where the dip is more than 35 degrees, hogback ridges replace the cuesta. The latter is the more usual landform developed where the dip is gentler. A great valley, termed the Red Valley, has formed between the limestone ridges of the Black Hills and the Dakota Hogbacks. This valley entirely encircles the Black Hills and was known to the Sioux as the Racetrack. Sioux legend states that men won dominance over the buffalo

and other animals by winning a race around this great "Racetrack", and that the red rocks of the Permo-Triassic Spearfish Formation represent the blood of the animals and humans as their feet bled from wear.

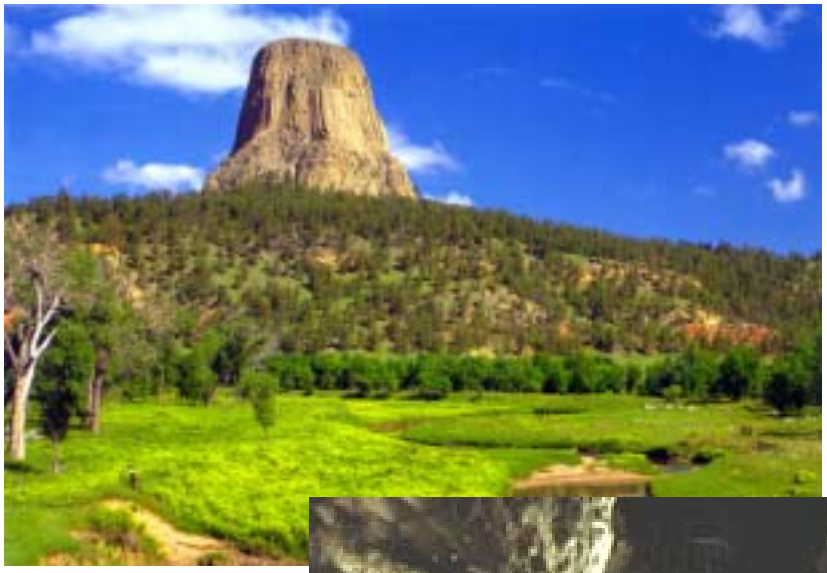
Other National Park Areas Nearby

Devils Tower National Monument, Devils Tower, Wyoming: Igneous petrology and columnar jointing make this a great area to take students on a fieldtrip. The Tower is a record of now extinct volcanism. Days could be spent at the Tower, but the Tower Trail will take no more than 1 hour. Call (307) 467-5283 for more information.

Jewel Cave National Monument, Custer, South Dakota: Very delicate speliothems, in conjunction with professional lighting, make the Jewel Cave Tour very enjoyable. Spelunking tours are available in the summer. Call (605)673-2288 for more information.

Theodore Roosevelt National Park, Medora, North Dakota: Badlands landscapes are manifested here in the Fort Union Group. The landscape may not be as "bad" as the White River Group badlands, but an abundance of petrified wood and coal seams make this a must see park. An added bonus of Theodore Roosevelt National Park is the adjacent Little Missouri National Grasslands. Rock hounds may collect petrified wood on the National Grassland. Ask at the T.R.N.P. visitor center for a Grassland visitor guide. Call (701) 623-4466 for more information.

Wind Cave National Park, Hot Springs, South Dakota: Speliothems are limited to box work in Wind Cave, but the abundance of the phenomena makes quite an impression. Call (605) 745-4600 for more information.



Devils Tower National Monument, Wyoming

Jewel Cave National Monument, South Dakota